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Europa's radiation environment and implications for surface composition

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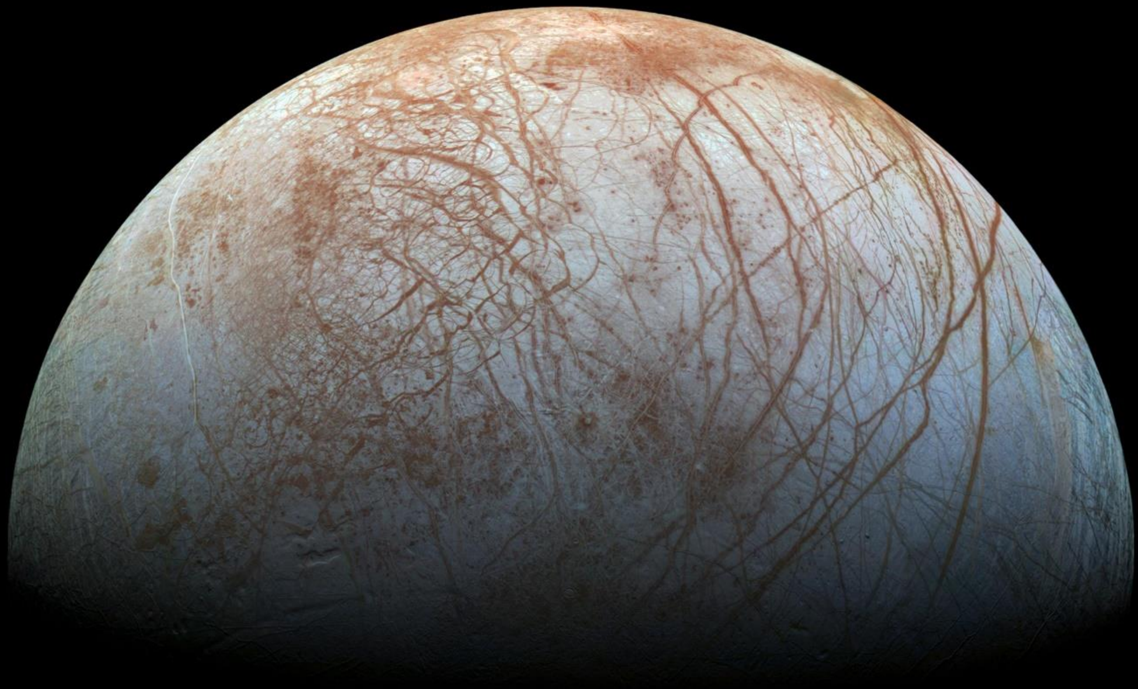
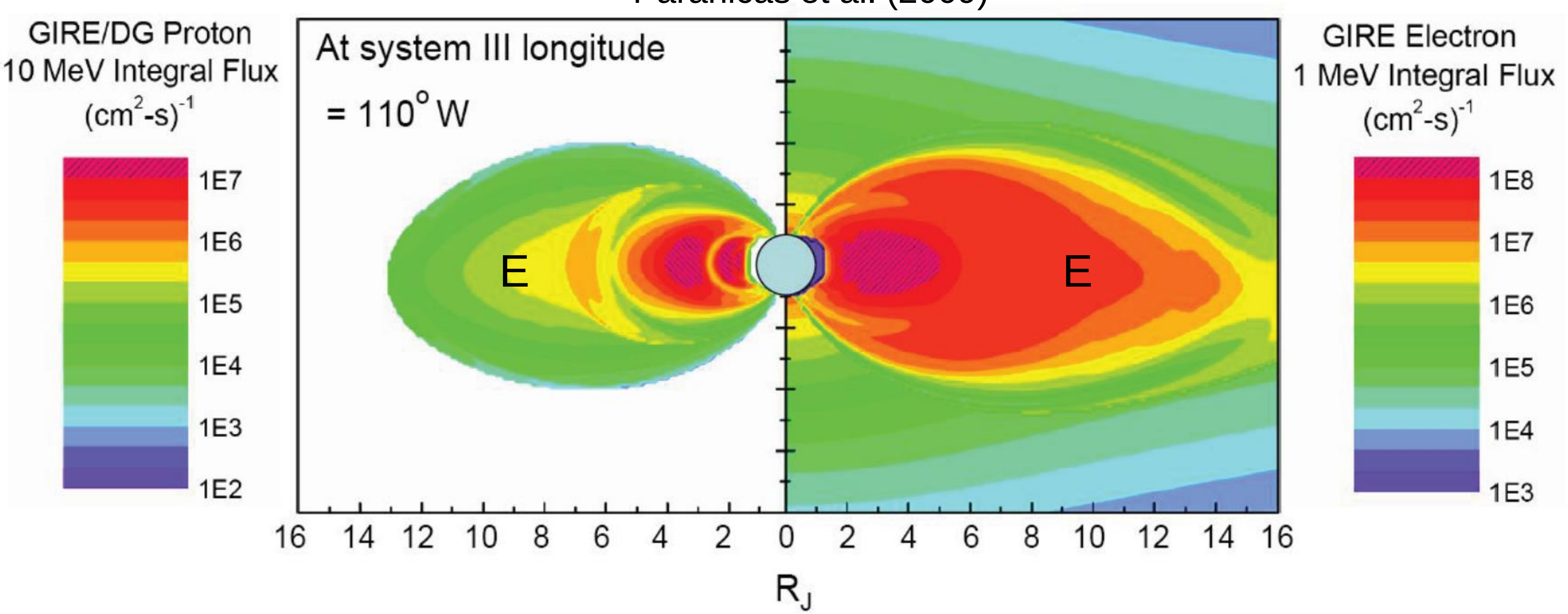


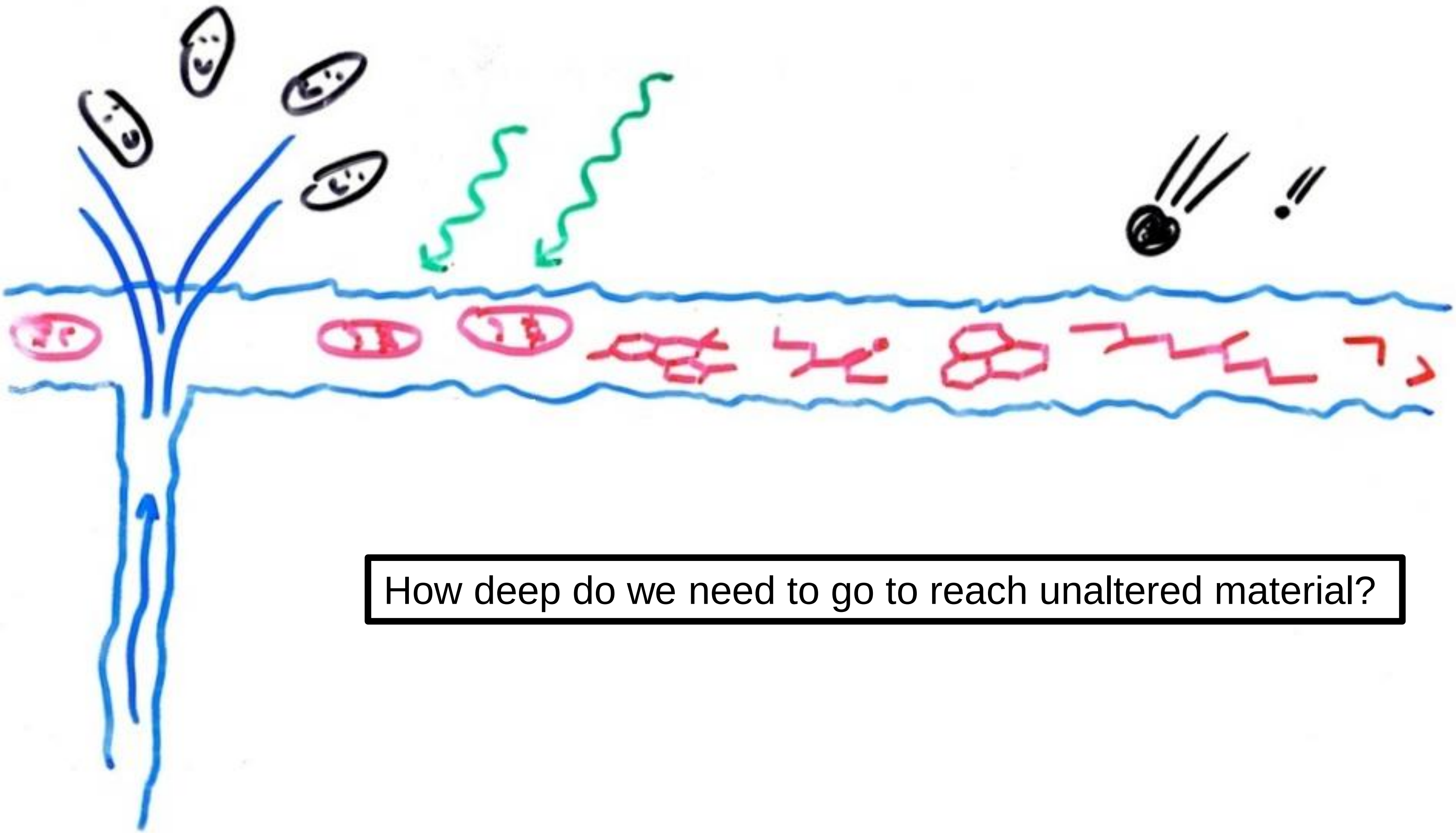
Europa radiation environment

Paranicas et al. (2009)



- Europa orbits within the Jovian radiation belts
- Surface is exposed to high flux of energetic charged particles
- Electrons, protons as well as oxygen and sulfur ions
- Energies up to ~100s of MeV
- Range of Sulfur and Oxygen ions ~mm
- **Electrons and protons primary contributors of dose at depth**

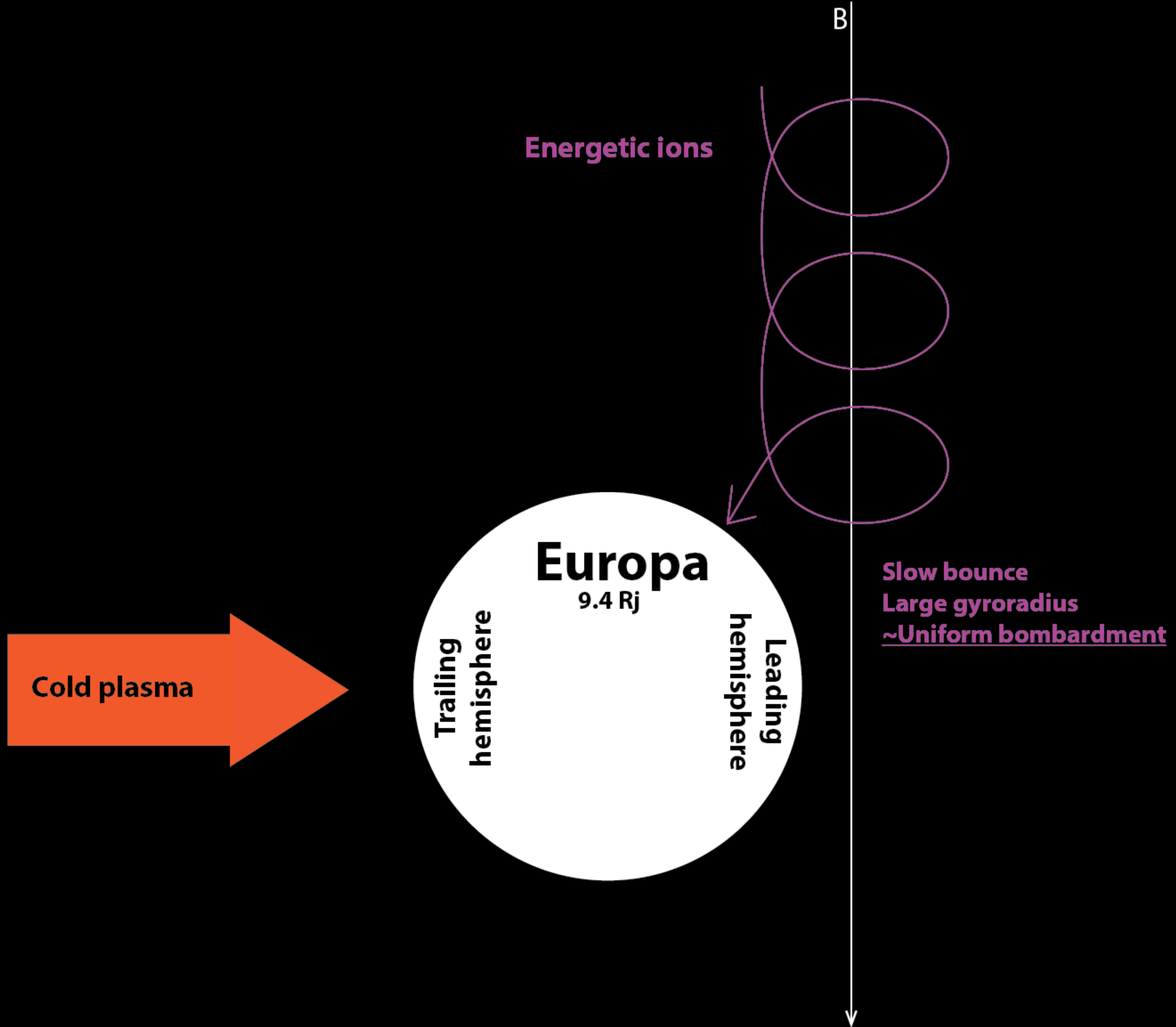
Life Detection on Europa
Biosignatures vs. Abiotic Radiolytic Chemistry

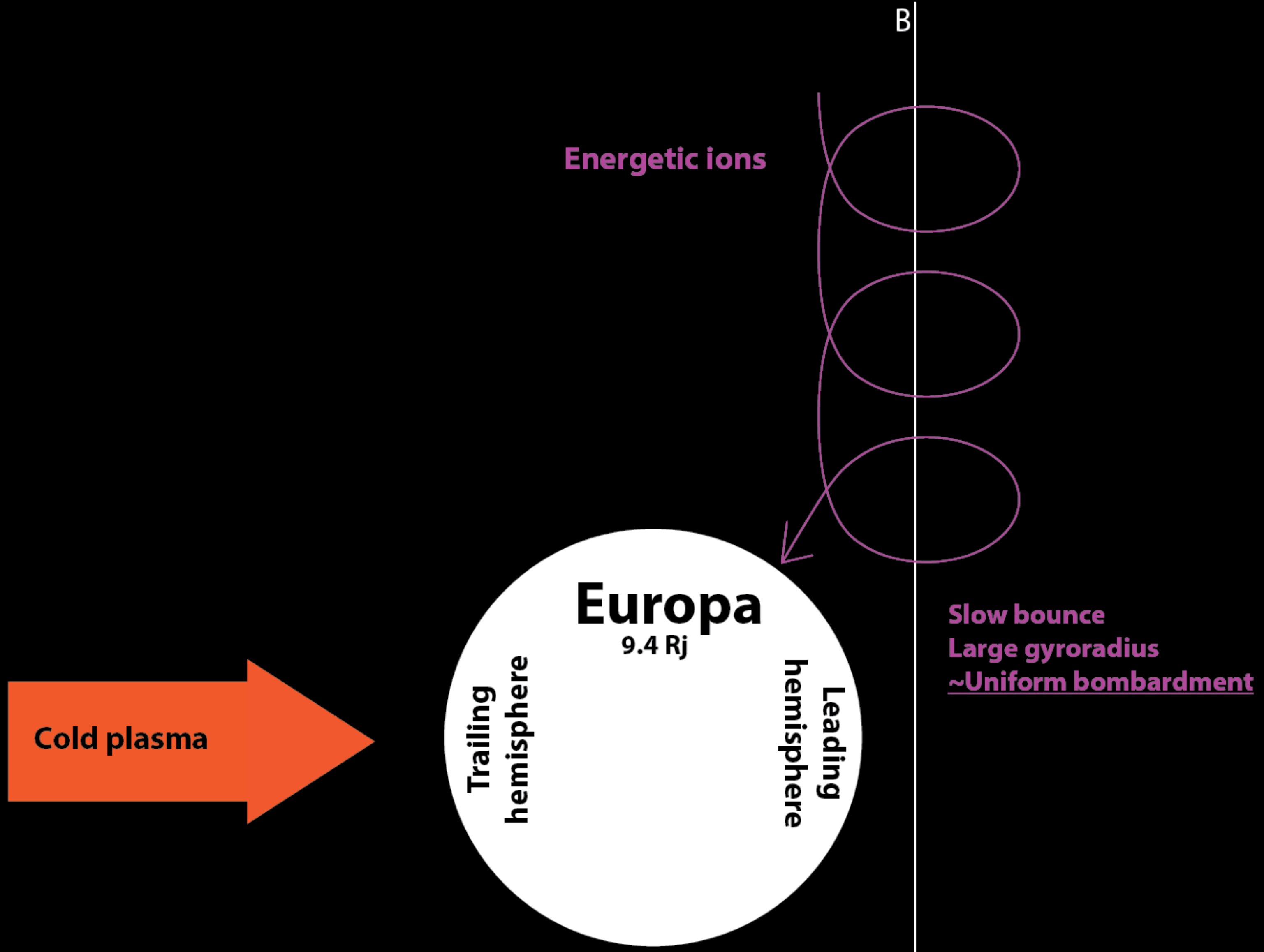


How deep do we need to go to reach unaltered material?

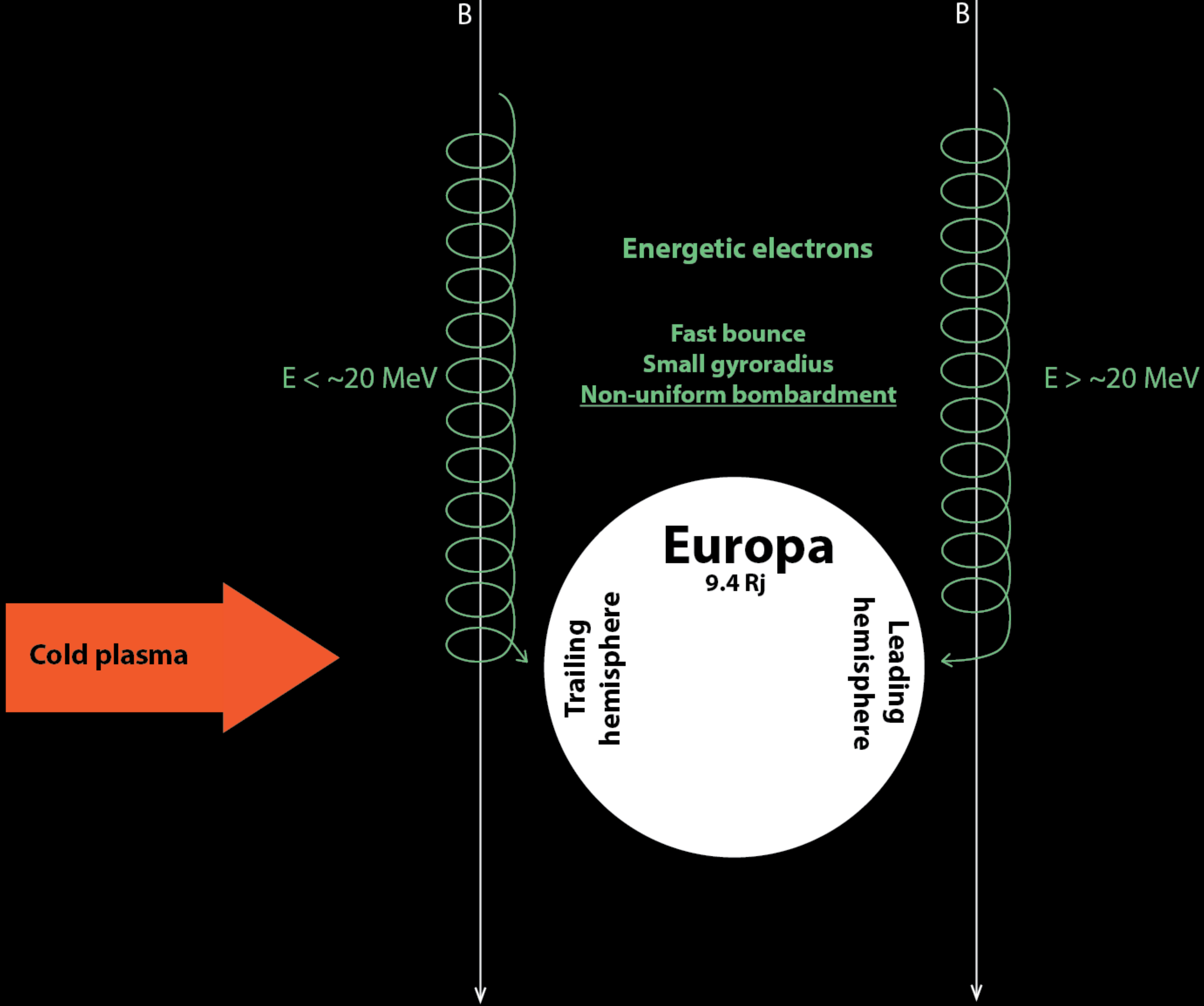
Illustration: K.P. Hand

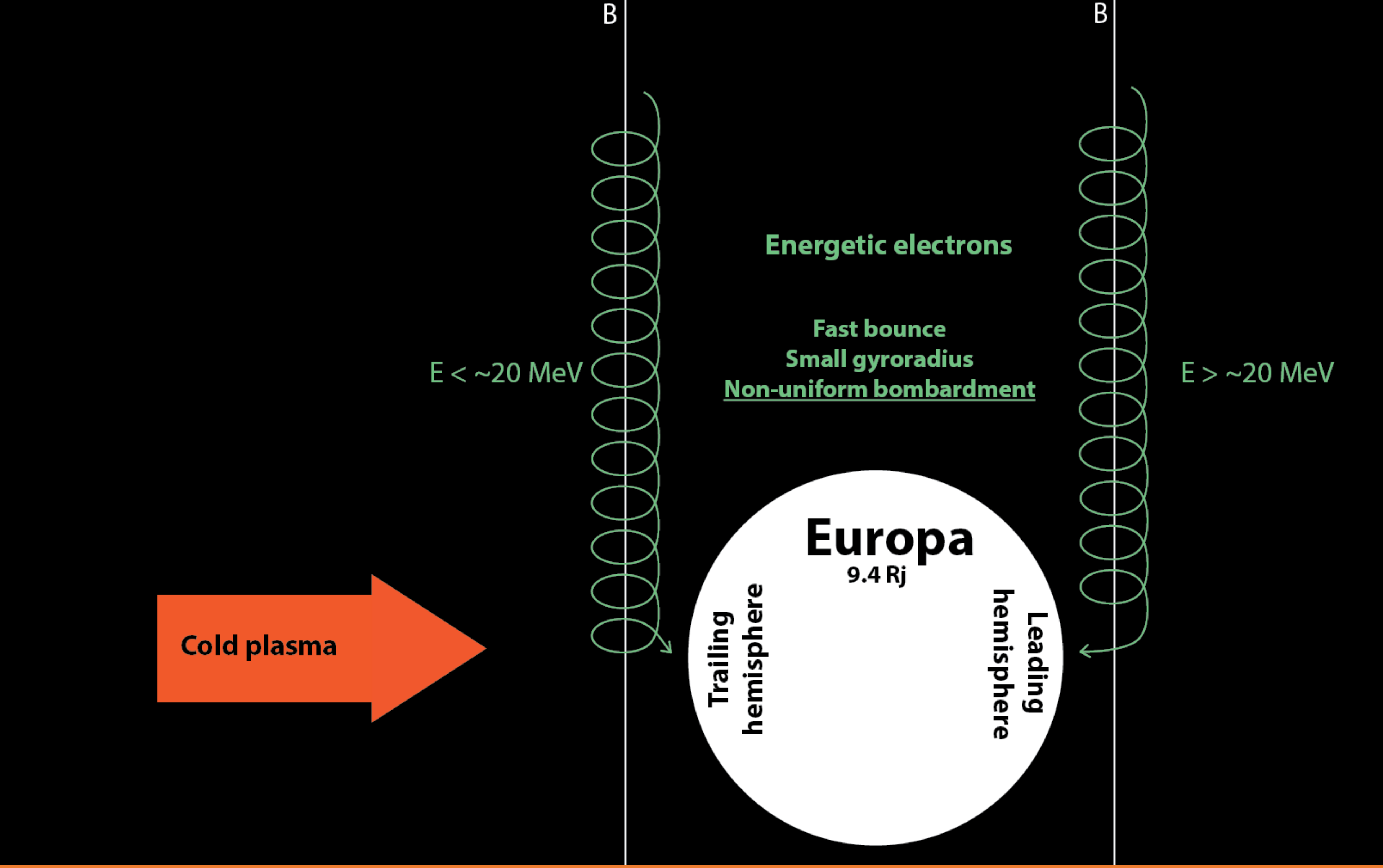

EUROPA LANDER STUDY 2016 REPORT
EUROPA LANDER MISSION
JPL D-97667
TASK ORDER NNN16D011T
EUROPA LANDER MISSION PRE-PHASE A


B
Energetic ions
Europa
9.4 Rj
Trailing hemisphere
Leading hemisphere
Cold plasma
Slow bounce
Large gyroradius
~Uniform bombardment



Energetic ions (including protons) will bombard the surface of Europa relatively uniformly due to their large gyroradii and slower bounce speed compared to energetic electrons

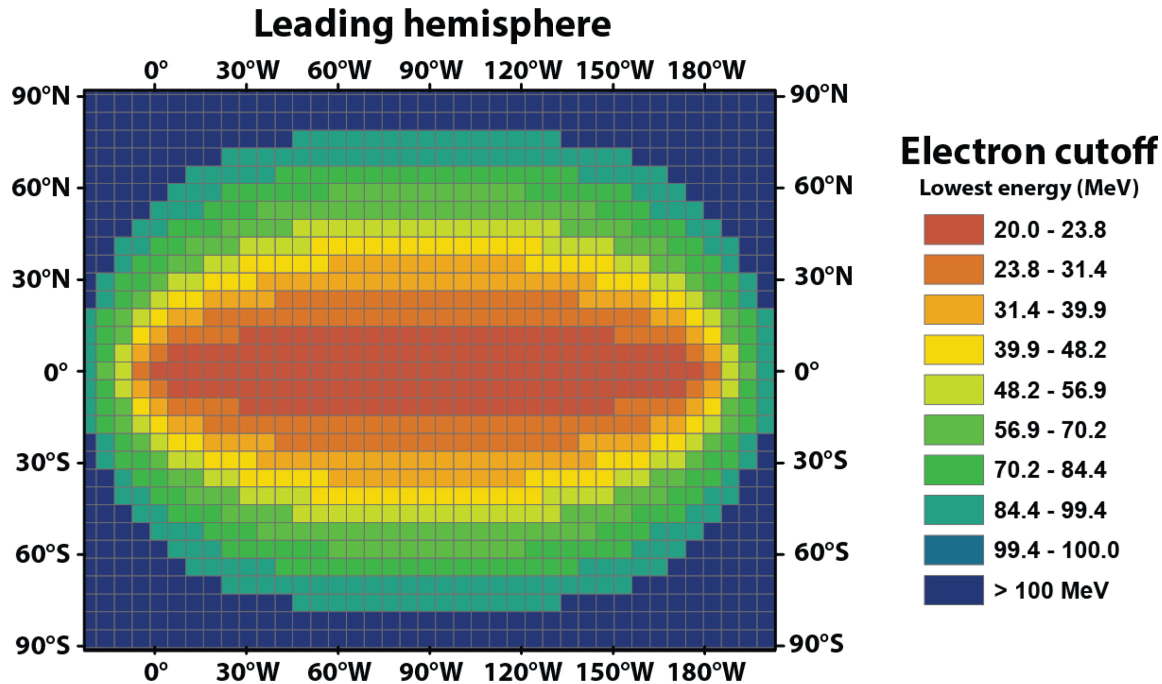

B
B
Energetic electrons
Fast bounce
Small gyroradius
Non-uniform bombardment
E < ~20 MeV
E > ~20 MeV
Europa
9.4 Rj
Trailing hemisphere
Leading hemisphere
Cold plasma



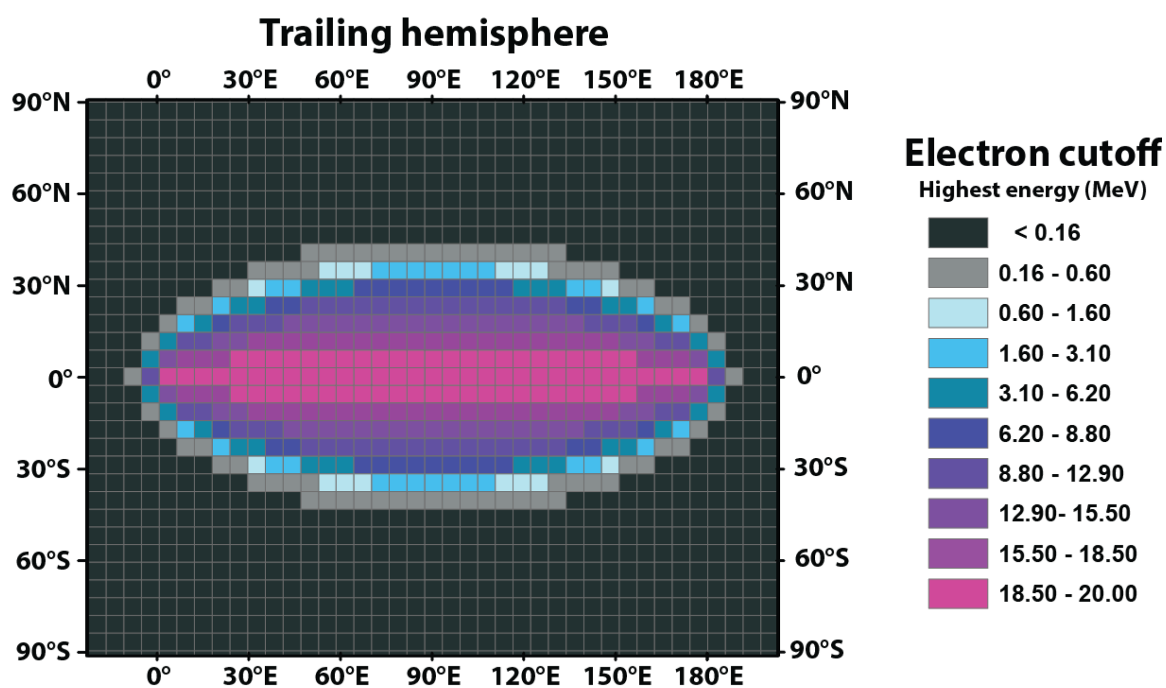
Energetic electrons have fast bounce times and small gyroradii (compared to the size of Europa). Their bombardment pattern is therefore highly non-uniform.

Nordheim et al. (2018)

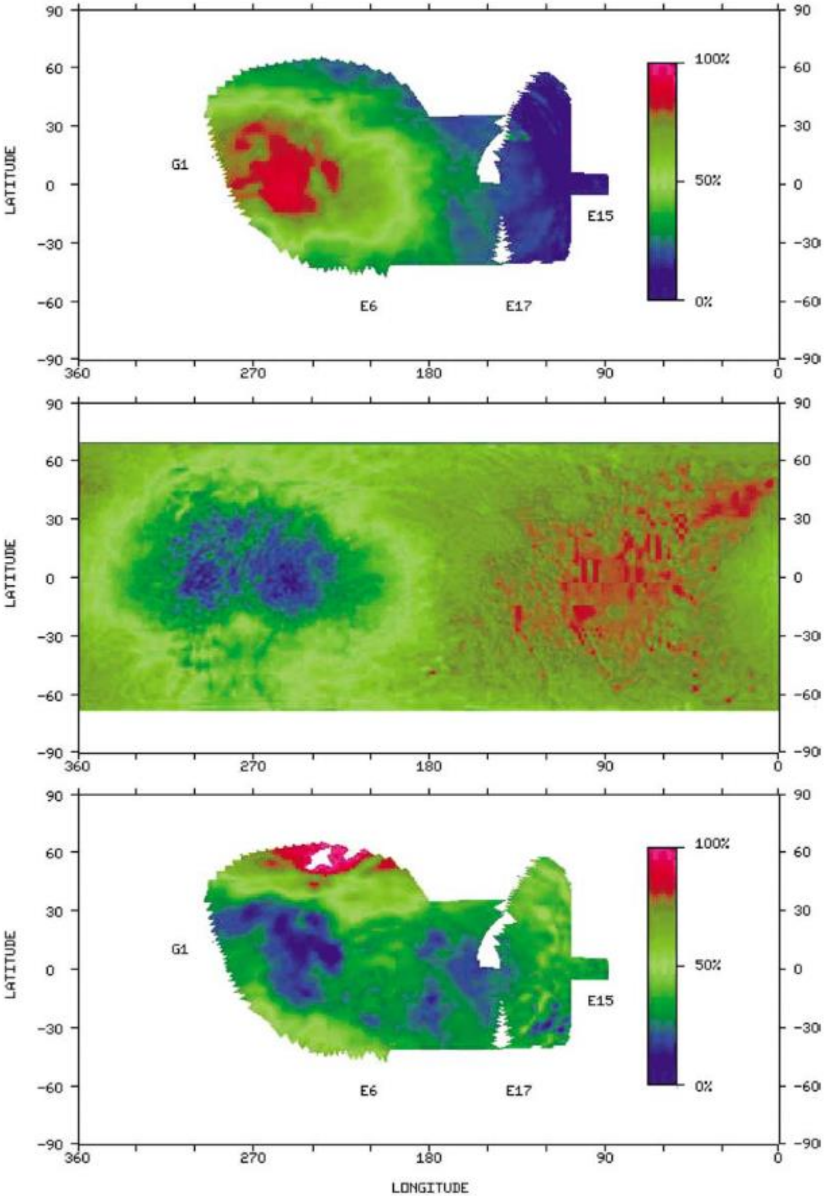
At the **leading hemisphere** the cut-off energy represents the **lowest** energy electrons within the 20 – 100 MeV range that can reach that location.



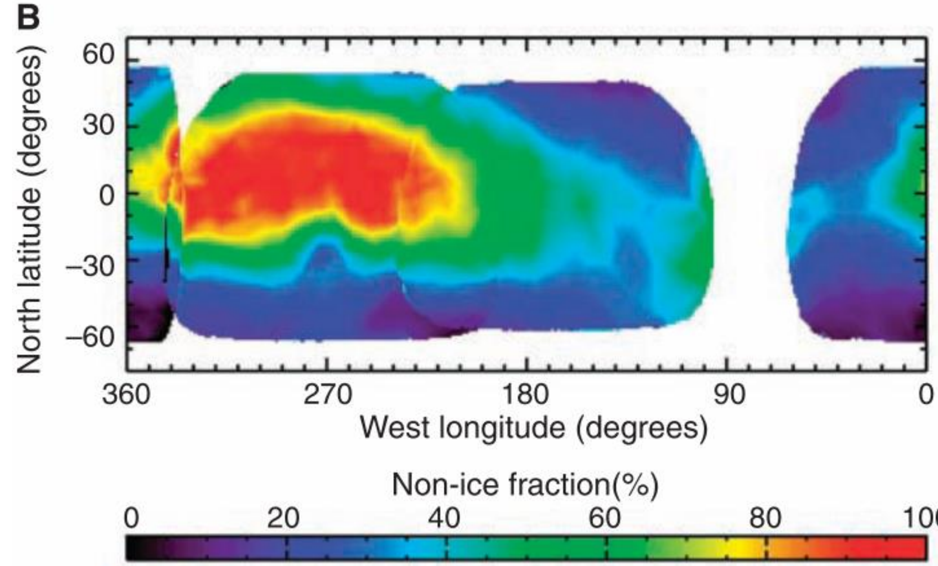
At the **trailing hemisphere** the cut-off energy represents the **highest** energy electrons within the 10 keV – 20 MeV range that can reach that location.



Observational support for lens

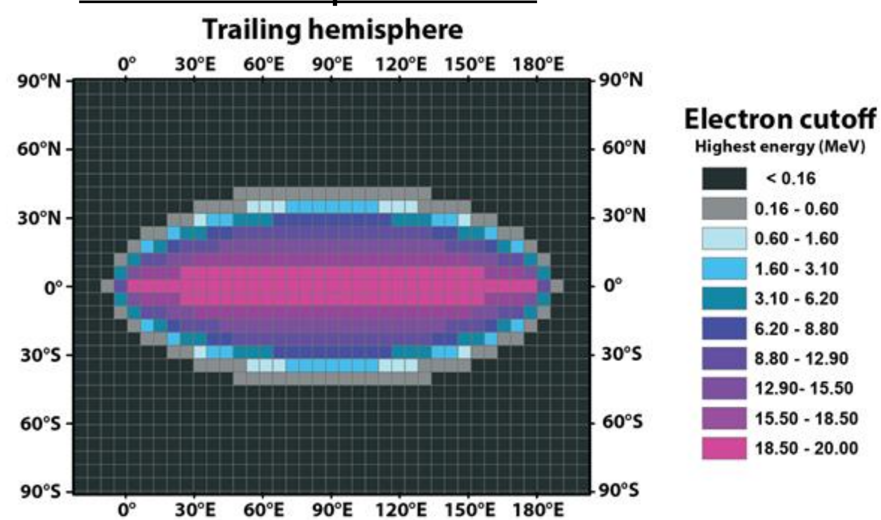


Carlson et al. (2005)



Grundy et al. (2007)

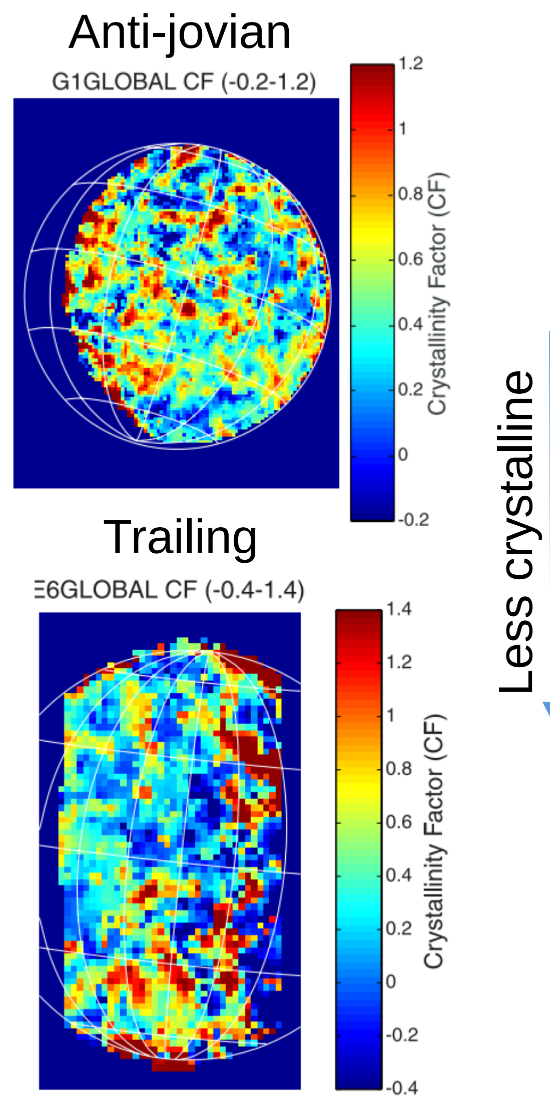
Theoretical prediction



Nordheim et al. (2018)

Amorphous ice on Galilean satellites

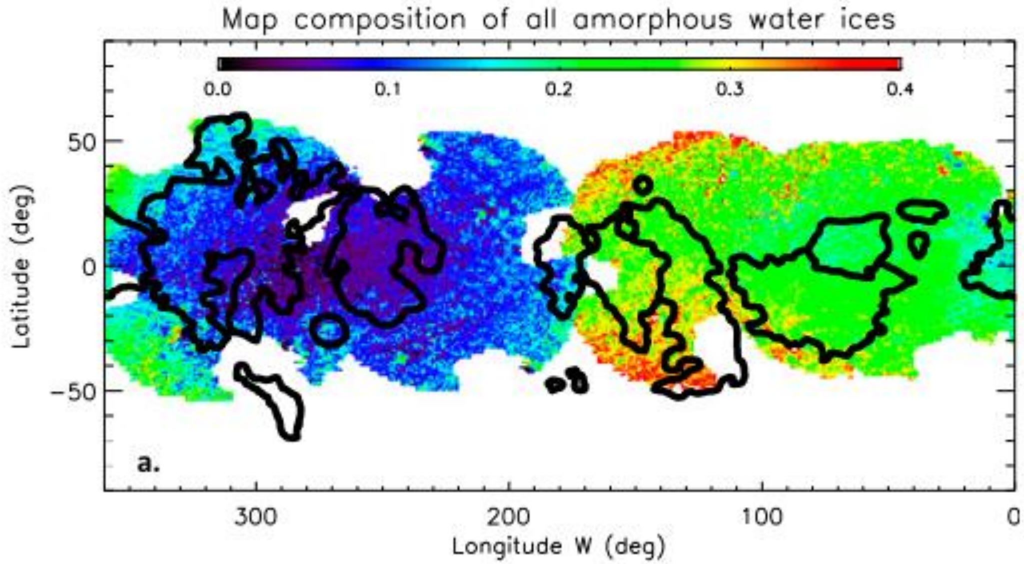
- Hansen & McCord investigated presence of A. ice on Galilean satellites using NIMS
- In top few um (based on 3.1 µm feature):
  - Europa is predominantly Amorphous
  - Callisto is predominantly Crystalline
  - Ganymede has a mix of both with the largest amount of A. ice on the low latitude trailing hemisphere and high latitude sub-jovian hemisphere
- At 1 mm depths (based on 1.65 µm feature):
  - Ice on all three satellites is predominantly crystalline
  - Strong indication that ions are responsible due to their shallow penetration depths.
  - Possibly implicates heavier ions over protons



Hansen & McCord (2004)

Distribution of A. ice at depth on Europa

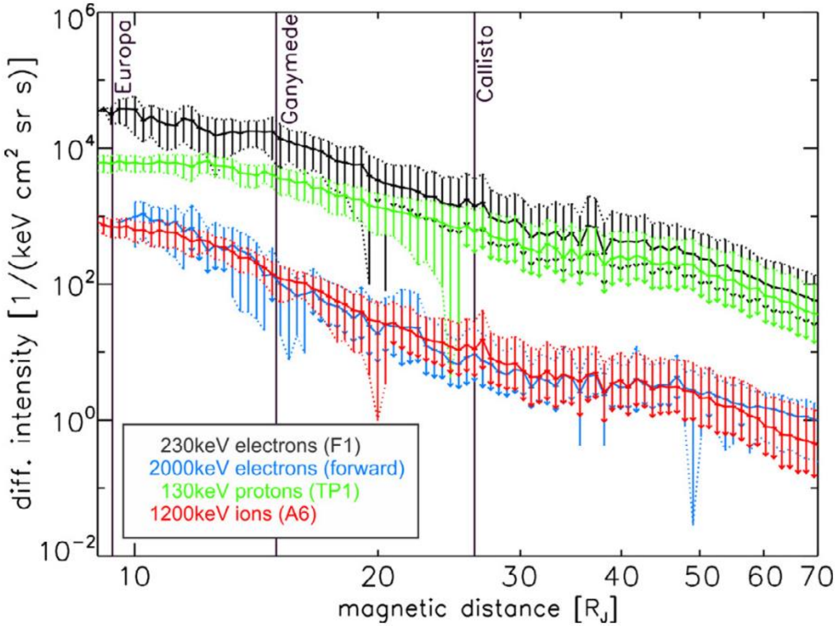
- Ligier et al. observed Europa using VLT
- More complete map of amorphous ice using 1.65μm band (~1mm)
- Found higher abundance of amorphous ice at depth on leading hemisphere
  - <u>More water ice present there!</u>
- More amorphous ice at higher latitudes



Ligier et al. (2016)

Radial distribution of Amorphous ice

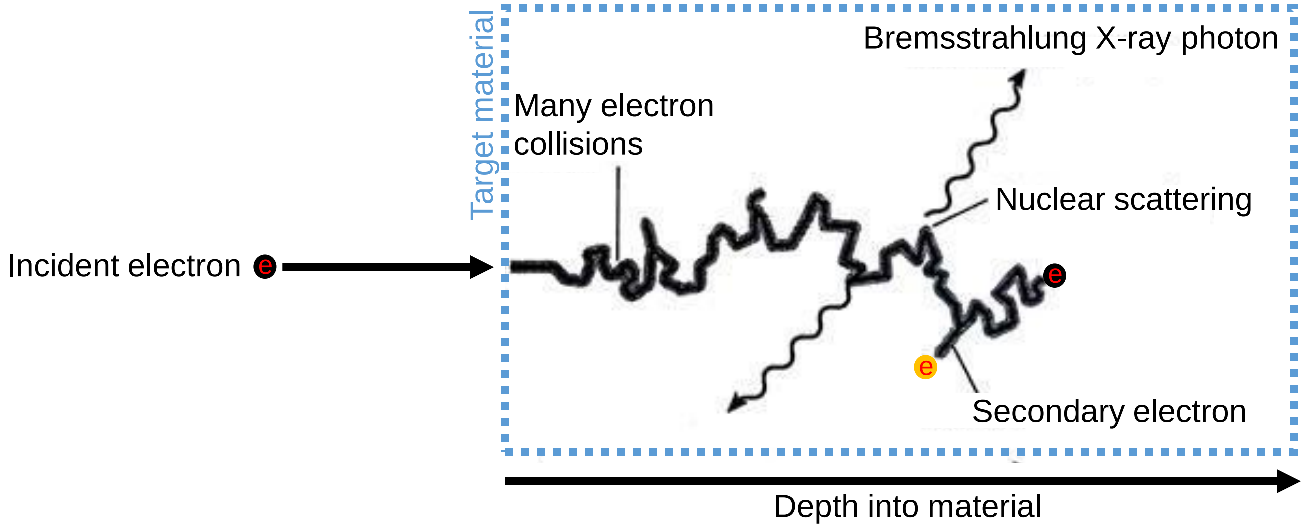
- Trend of decreasing abundance of A. ice with radial distance
- Consistent with the dropoff in ion flux
- Radiation environment is 10x higher at Ganymede than Callisto
- Radiation environment is 32x higher at Europa than Ganymede

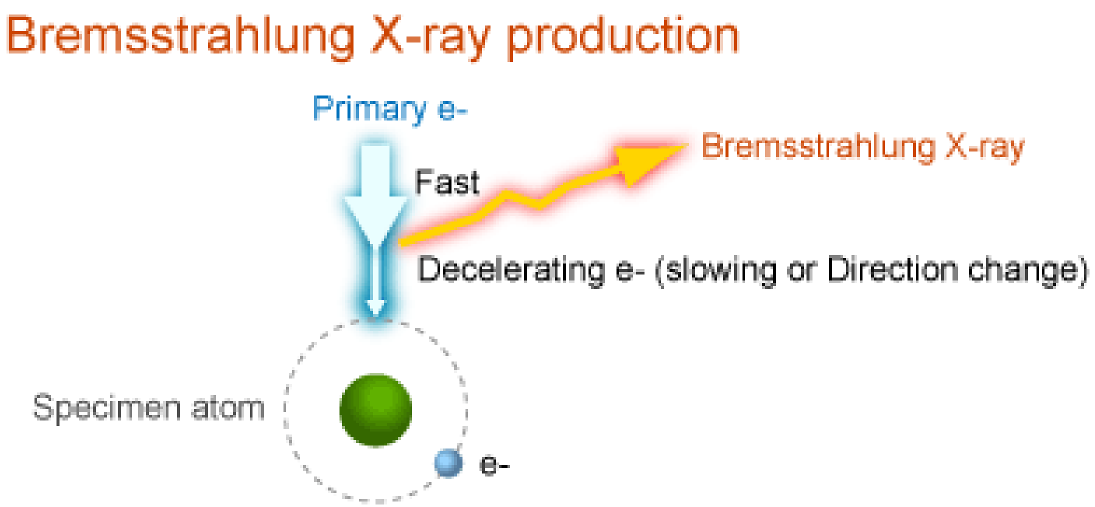


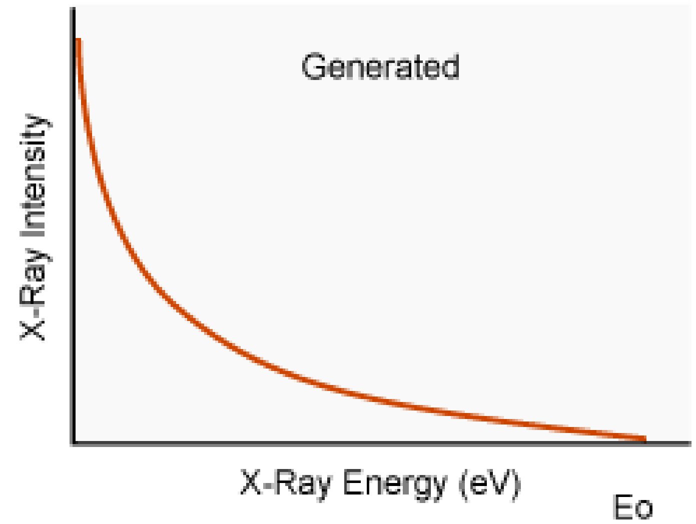
Paranicas et al. (2018)

“ How deep does radiation penetrate on Europa?”

- This is not really a meaningful question to ask
- For example, 100 MeV electrons can penetrate to depths of 10s of cm, however their flux is <u>very low</u>
- <u>Incident charged particles produce secondary particles - > these can reach larger depths than the primary</u>
- The relevant quantity is the <u>radiation dose</u> deposited in material at a given depth and location by primary and secondary particles

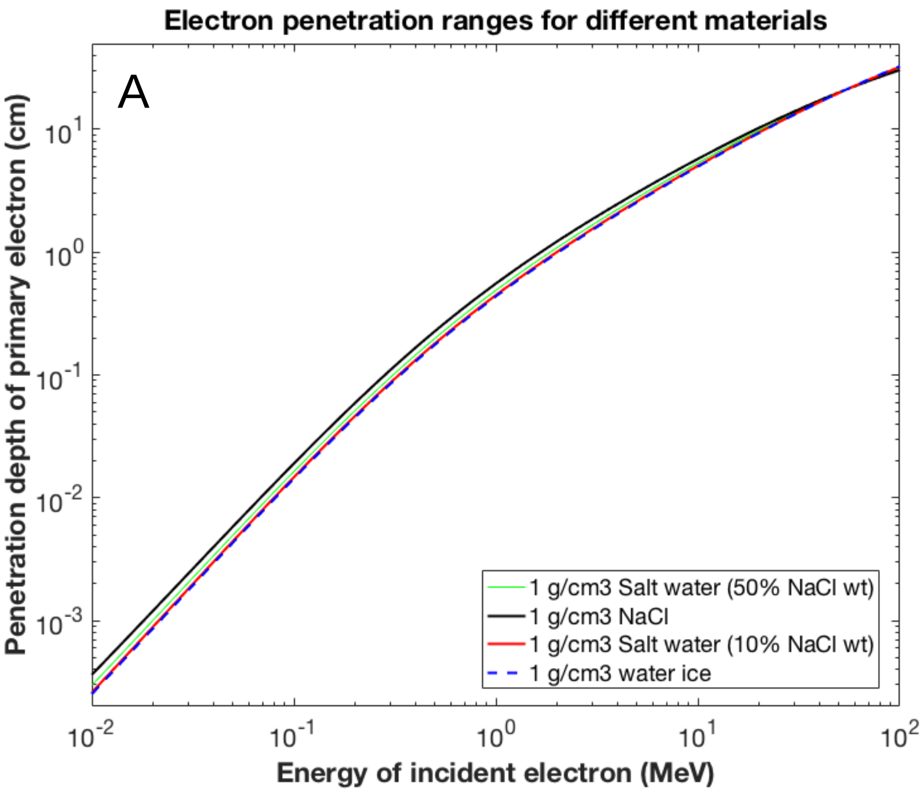


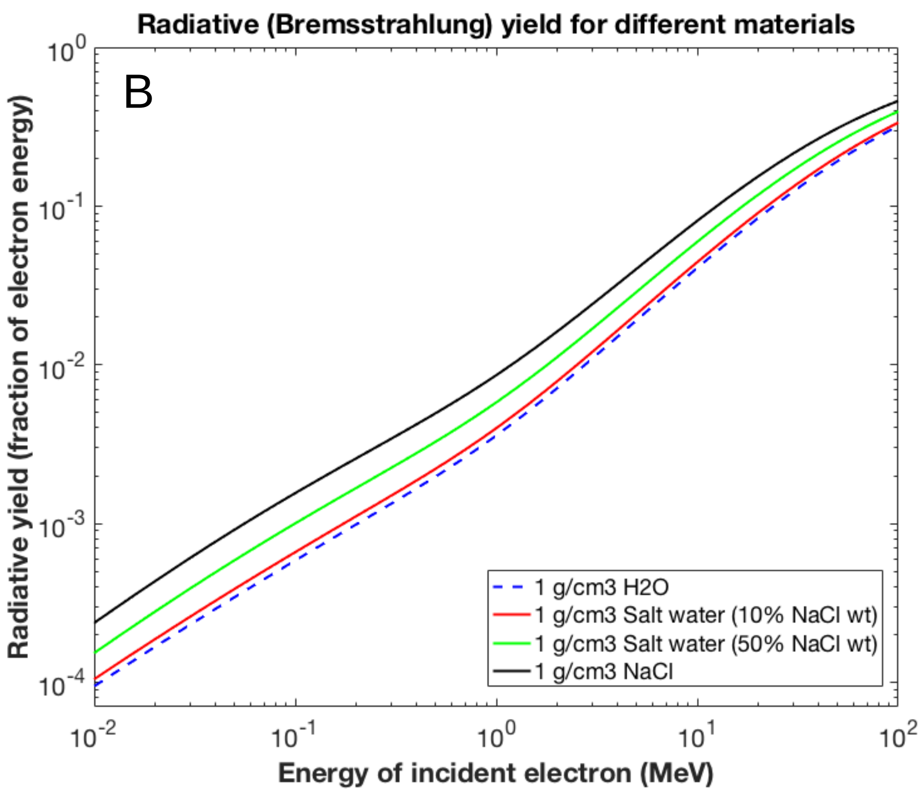




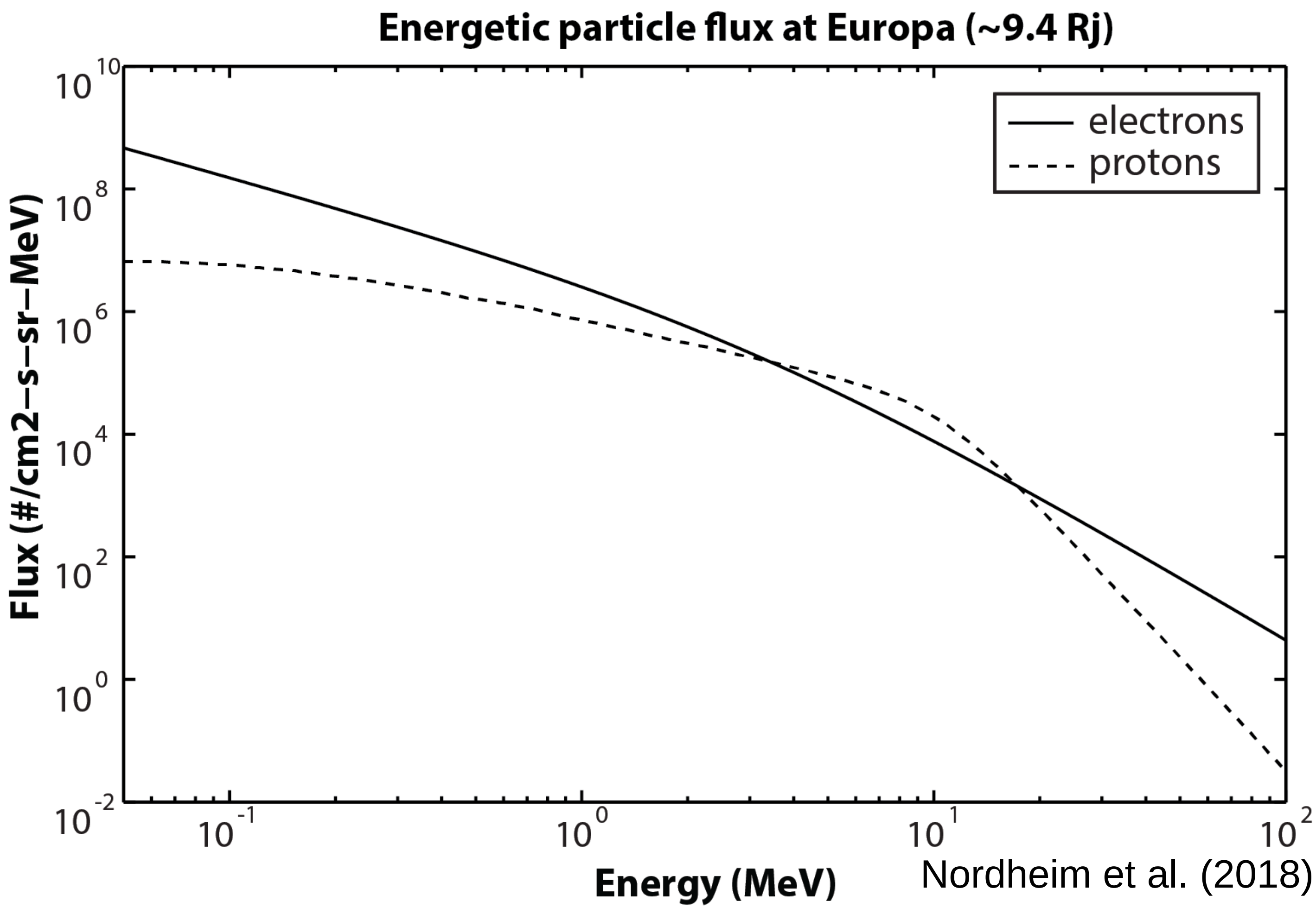
- **Incident electrons generate secondary Bremsstrahlung (X-ray) photons**
- **Energy of Bremsstrahlung photons is a continuum from 0 to E_O**
- **Highest possible Bremsstrahlung photon energy is the energy of the original electron (E_O)**
- **Bremsstrahlung photons can have a much larger range in the material than the original electron**
- **The fraction of the electron energy E_O that is converted to Bremsstrahlung ("radiation yield") increases as Z goes up**
- **Bremsstrahlung yields depend on material type (Kramer's law)**

Image: ammrf.org.au





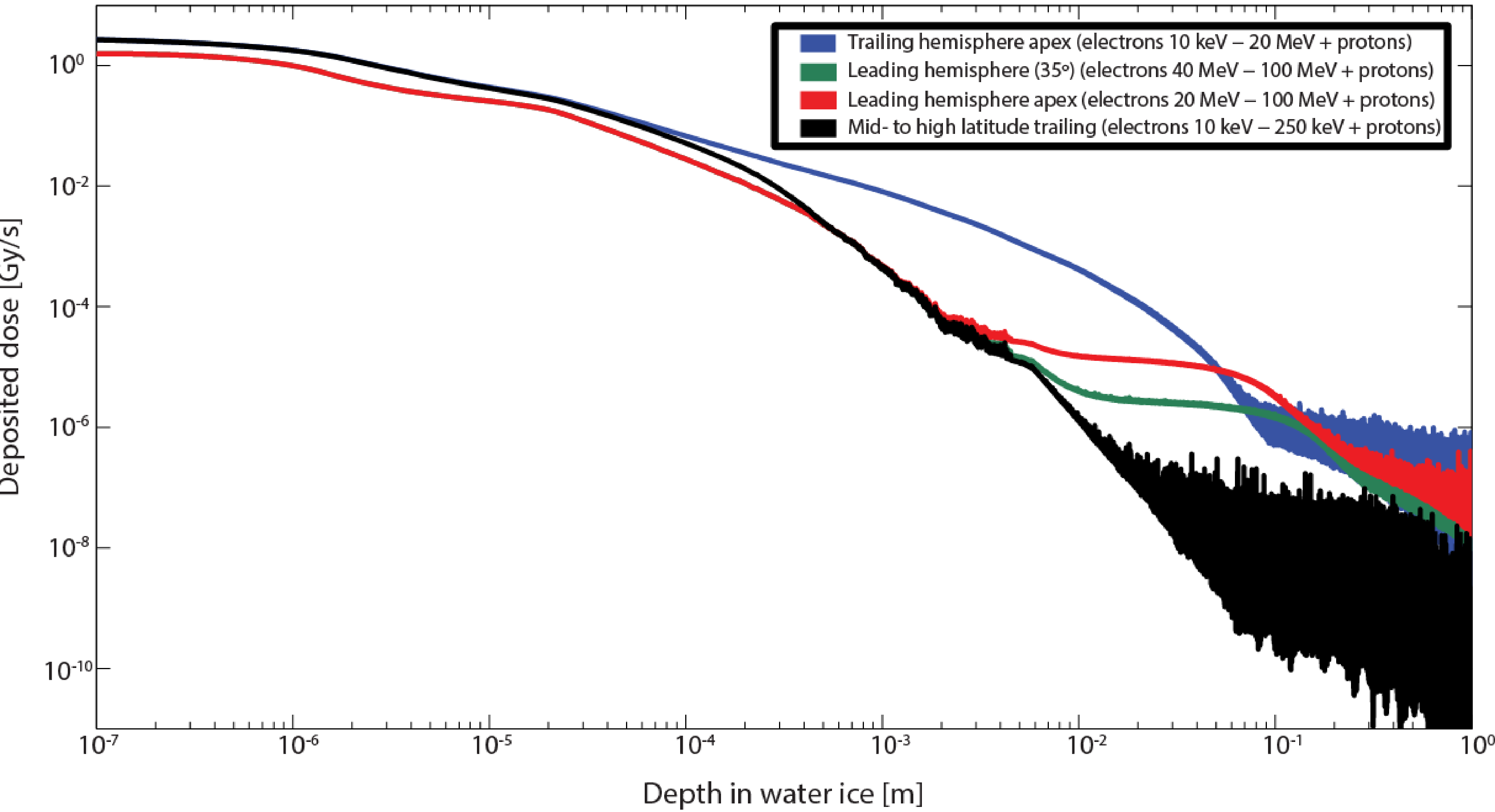
- <u>Electron penetration ranges</u> (A) are not strongly affected by the material composition
  - Penetration depth will scale ~linearly with density (e.g. salts more dense than H_2O)
- <u>Bremsstrahlung yields</u> (B) increase with increasing atomic number (Z)
  - Simple linear density scaling not sufficient to account for differences



Nordheim et al. (2018)

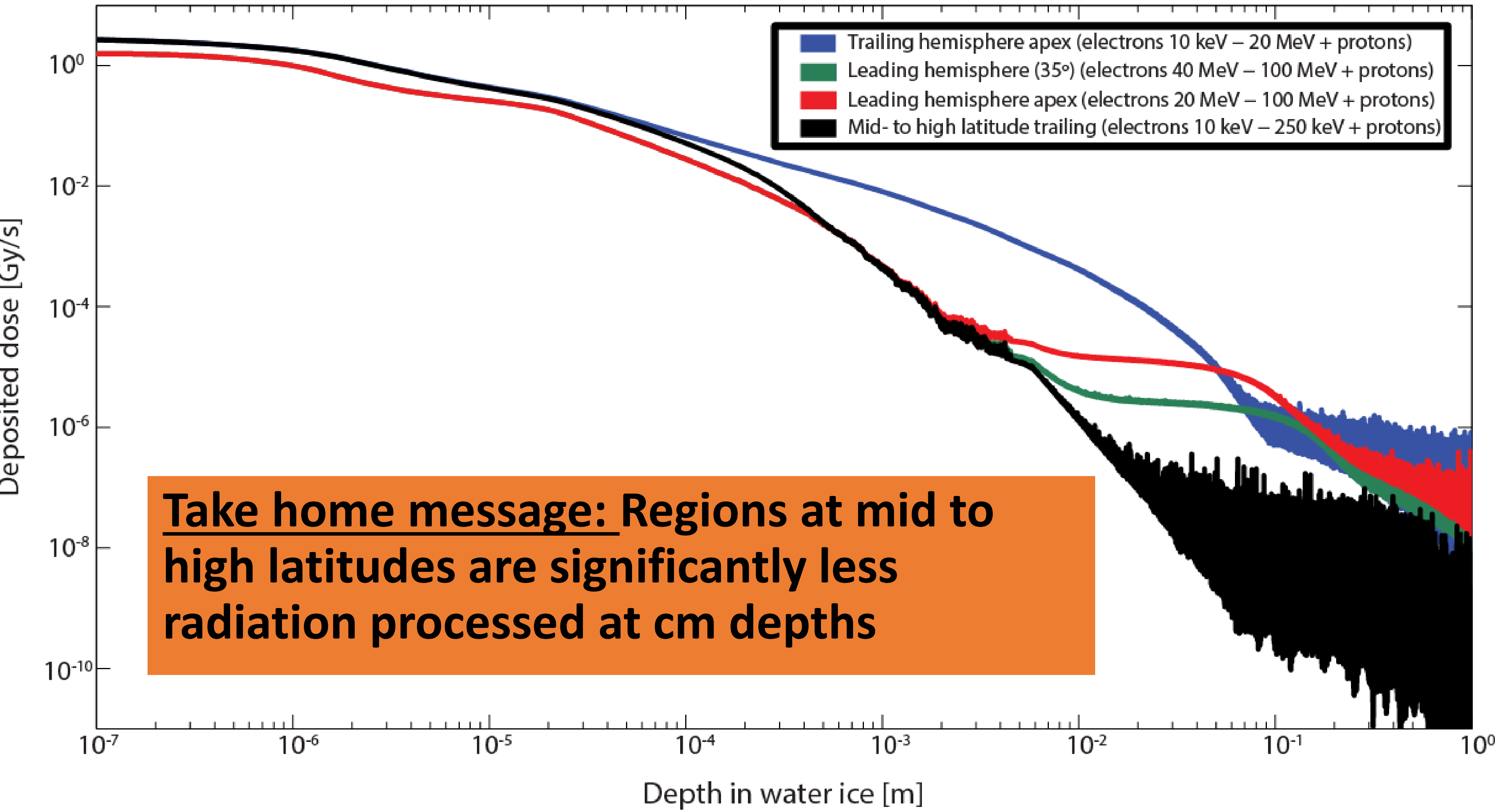
- Average energetic electron and proton spectra at Europa's L-shell.
- Fits to Galileo EPD and Voyager LECP data

Nordheim et al. (2018)



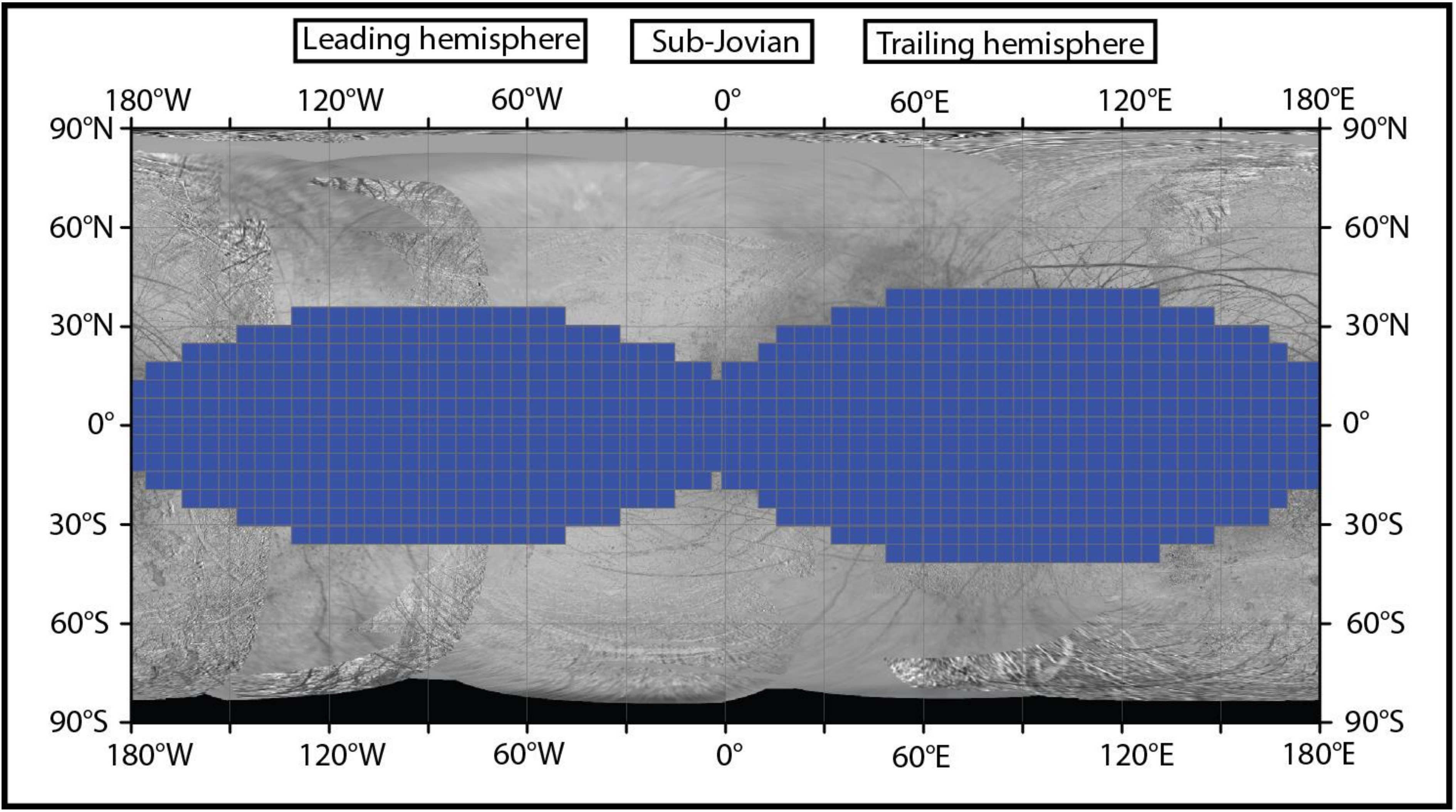
1 Gy = 100 Rad

Nordheim et al. (2018)



<u>Take home message:</u> Regions at mid to high latitudes are significantly less radiation processed at cm depths

1 Gy = 100 Rad



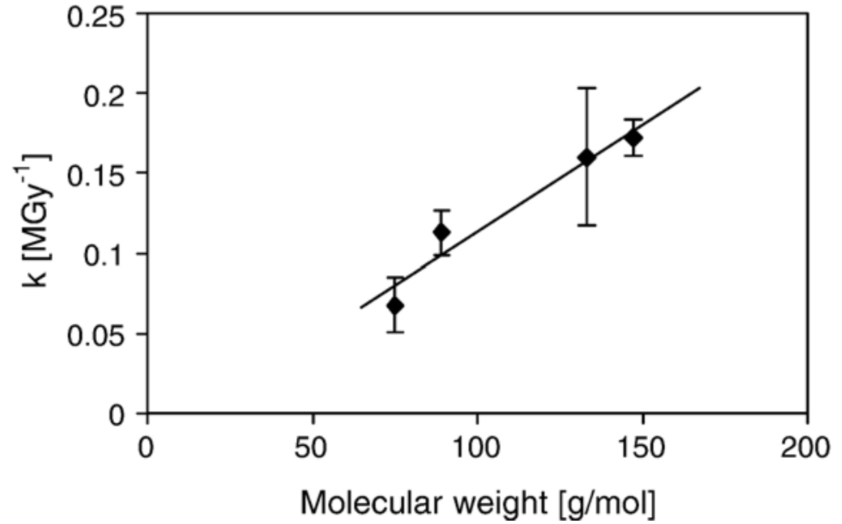
Nordheim et al. (2018)

Locations that have been radiation processed to at least 10 cm depth in 10 Myr*

*reached a dose of 100 eV/16 amu (600 MGy) over 10 Myr

Biosignature destruction – amino acids

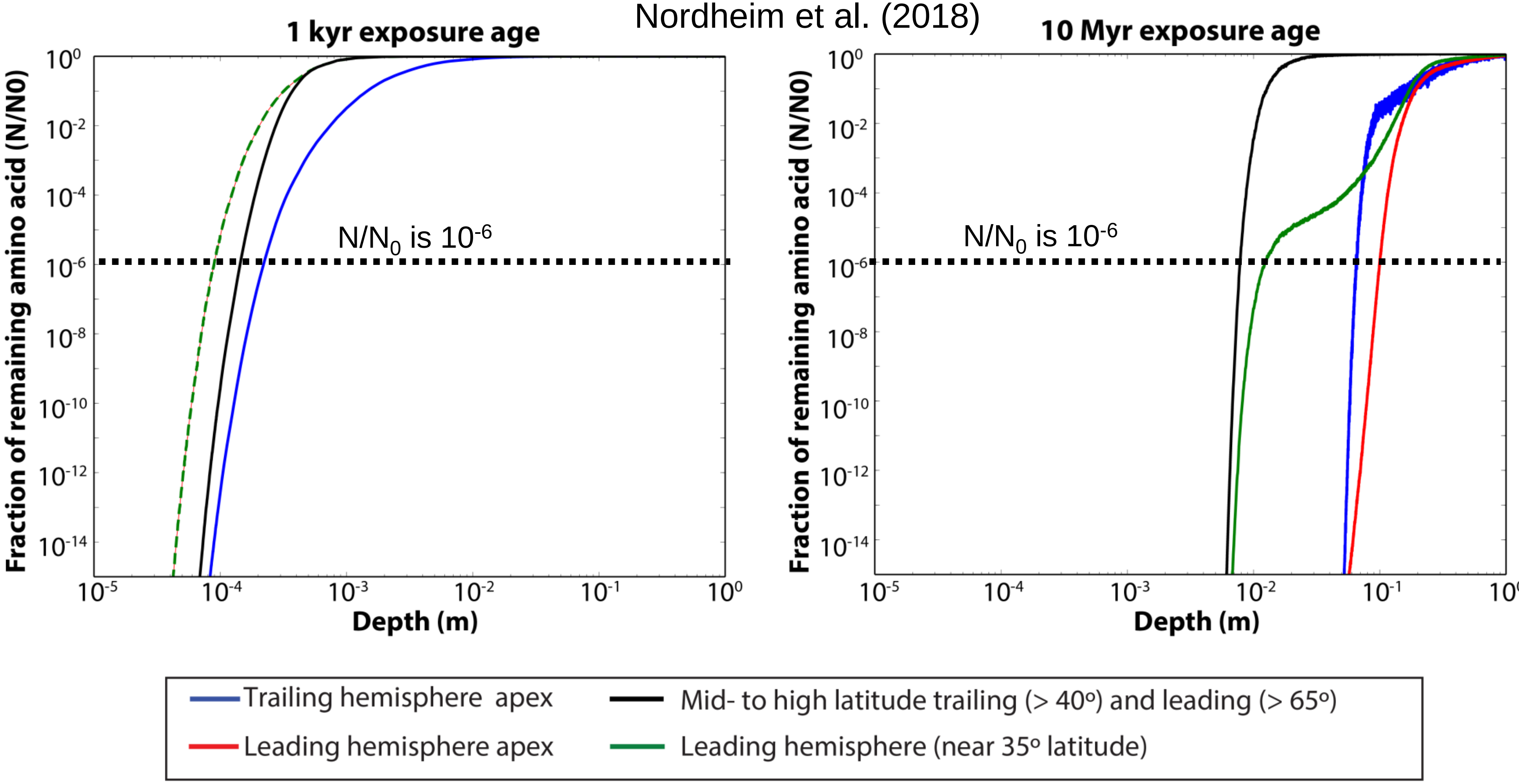
- We have considered the destruction of amino acids as a case study for potential biosignature destruction
- Amino acids are not strictly a sign of life but they could serve as one of the simplest molecules that qualifies as a potential biosignature.
- Amino acids are the building blocks for proteins and they have been well-studied in the context of survival on Mars and other targets of astrobiological interest(Kmniek & Bada, 2006, Gerakines et al., 2012, 2013)



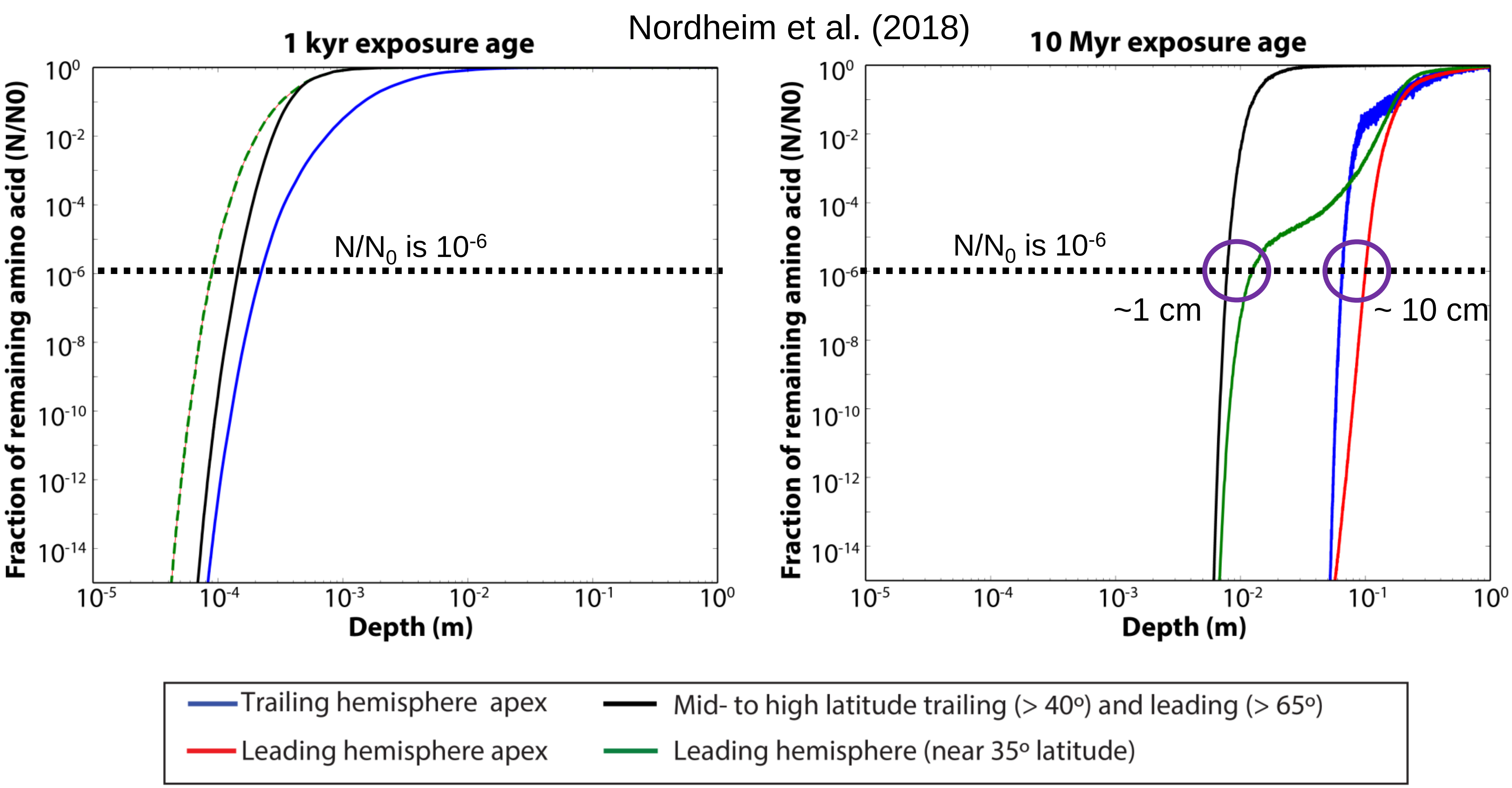
Kmniek & Bada (2006)

Survivability of biosignatures

Nordheim et al. (2018)



Take home message: Biosignatures are better preserved at mid to high latitudes and in young (<10 Myr surface material)



Summary

- **Electron bombardment patterns are crucial to understanding the surface dose**
- **Uppermost layers of surface heavily radiation processed down to 10-20 cm depths near leading and trailing apex**
- **Regions outside leading/trailing electron “lenses” significantly less irradiated – allows for shallower sampling depths**
- **Biosignatures detectable (N/N_0 >10^{-6}) at 10 cm depth regardless of surface location**
- **At shorter exposure times (<10 Myr) and at mid- to high latitudes, biosignatures may be well preserved even at shallow (cm or less) depths**